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# The oxygen transfer efficiency and economic cost analysis of aeration system in municipal wastewater treatment plant

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**Abstract**

This paper mainly discussed the oxygen transfer efficiency and economic cost of aeration system in one of Wastewater Treatment Plant (WWTP) in Shandong province. The Standard Oxygen Transfer Rate (SOTR) of new and old aerator of aeration system in this WWTP was studied in this paper firstly. The results show that the SOTR of the older aerator were reduced obviously, and the reason of this phenomenon is that the micro-porous in the membrane has damaged and blocked. The cost analysis of the aeration system combining with the actual operation of this WWTP was also studied, conclusions were got that 0.9 million Yuan can be saved each year after replace the old aerator which has already run more than 10 years. Furthermore, this replacement can recovery its cost after only 14 months.


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*Keywords*: Aeration system, Cost analysis, Energy saving, Standard Oxygen Transfer Rate

## 1. Introduction

As the main structures in aeration wastewater treatment process, aeration tank occupied the important position in today's wastewater treatment technology. The energy-intensive costs generated in the operation process become more and more important in WWTP operation today, so the research on this problem is of great significance [1]. Studies have been shown that the energy consumption of aeration system can account for 40%-60% of total energy consumption in WWTP [2-3]. In order to solve this problem, this paper researches the Standard Oxygen Transfer Rate (SOTR) between the new aerator and

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the old one in one of WWTP in Shandong province firstly. After that, the operational cost calculation and analyzed of the aeration equipments by the method which name is present worth also studied.

## 2. Materials and methods

### *2.1. Test on differences of SOTR between the new and old aerators*

The schemes of testing devices are shown in Fig.1， the volume of testing tank is 0.46 $m^3$, the micro-porous aeration diffuser is installed at the bottom of tank. The aeration rate is controlled by the gas flow-meter. The YSI and HACH on-line monitoring instrument records the change of dissolved oxygen value [4].

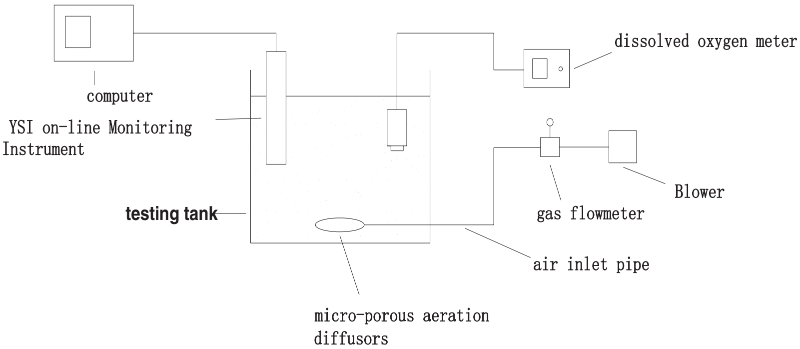


Fig.1 Experimental device schemes

### *2.2. Analysis method of aerator operation cost*

#### *2.2.1. Present worth method*

Present value method belong to dynamic value of evaluation indexes .The basis idea of present value is to convert the cost and benefit of scheme to the present value and get its difference value to get the benefit present value. The scheme economically viable if the value is greater than zero, otherwise not workable Compare the benefit present value of every scheme; the largest one is the best solutions [5-7].

The main steps of present value method are listed below:

1. Enumerated plan: list all the possible solutions.
2. Calculation the costs and benefits of each scheme: Choose the same price when calculate the costs .If considering the price changes, the same rate of inflation should also be adopted.
3. Choose the datum year: The same datum year should be choose for all the schemes.
4. Determine the analysis phase: The same analysis phase should be adopted for all the schemes
5. Determine the discount rates: Unified discount rates should be adopted for all the schemes.
6. Calculate the present worth of costs and benefits of all the schemes.
7. Calculate the net present value of all the schemes.
8. Choose the plan whose net present value is biggest one as the final plan.

### *2.2.2. The application ofpresent value method in aeration system cost account*

The total investment of aeration system included initial investment and operating costs. The initial investment is mainly for the purchase aerator expenses, aerator installation expenses, etc [8]. Operating cost is mainly for electric charge.

Assuming the oxygen utilization of the new aerator and old one are different, but the difference between the operating cost can compare. The formula of electricity operation cost convert to the benchmark year is showed as follows:

$$POCST = USOWF \times Wp \times UPC \times 24 \times 365 \tag{2-1}$$

$$POCST = OCST \times USOWF \tag{2-2}$$

OCST --- Year running electricity cost, Yuan;
Wp --- Aeration systempower, kw;
POCST --- Present value of total operating cost in N years, Yuan;
USOWF --- Coefficient of Present value, $[(1+I)^n -1]/[I(1+I)^n]$;
UPC --- Unit electricity cost, Yuan/kw·h;
N --- Aerator running time, Year;
I --- Interest Rate

The formula can be got from (2-1) and (2-2):

$$POCST = USPWF \times WP \times UPC \times 24 \times 365 \tag{2-3}$$

### *2.2.3. The operate data and aerator parameters of the WWTP*

1. Aerator ran time: 10 years;
2. Electric cost: 1.0yuan/kw • h;
3. Water inflow: $8\times10^4$ $m^3$/day;
4. The BOD concentration in influent: 350 mg/L-450 mg/L, take 400 mg/L;
5. The oxygen consumption per kilogram of BOD: 1.2 kg;
6. The $NH_4^+$-N concentration in influent: 50 mg/L;
7. The oxygen consumption per kilogram of $NH_4$-N;
8. Hydraulic retention time: 14 h;
9. Aeration area: 9333 $m^2$;
10. Local atmospheric pressure: standard atmospheric pressure value 101 kPa;
11. The set-point of DO: 2 mg/L;
12. The submerged depth of aeration equipment: 4.7 m;
13. α value(the ratio of oxygen transfer coefficient of aerator in wastewater and clean water): 0.5;
14. β value(the ratio of saturation dissolved oxygen concentration in wastewater and clean water): 0.95;
15. Oxygen use efficiency: new aeration equipment, 40%; old aeration equipment, 36.9%;
16. Valve resistance losses: theoretical value, 7.62 cm$H_2O$;
17. Aerator resistance losses: theoretical value, 25.4 cm$H_2O$;
18. The pipeline resistance losses: 45.72 cm $H_2O$;
19. The temperature of fan inlet: 20 ℃;
20. Fan efficiency: 95%

## 3. Results and discussion

### *3.1. Testing results and analysis of SOTR between new aerator and old one*

The oxygenation ability of aerator will decrease gradually with its increasing length of operation. The experiment analyzed the SOTR by comparing new aeration and old one which had already run for ten years. The comparative result is shown in Fig.2.

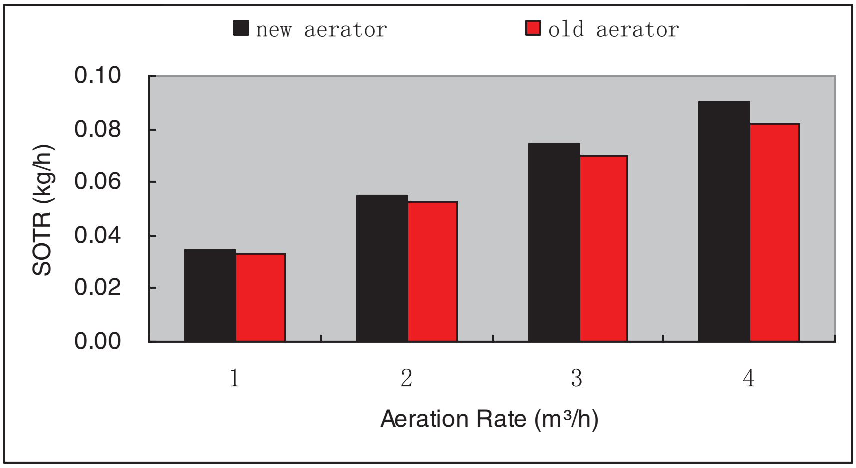


Fig.2 Test result of SOTR between new aerators and old ones

Compared with the new aerator, the SOTR of the aerator which had been in operated for ten years were reduced obviously. And as greater the aeration rate was, the larger difference of SOTR between the new aerator and the old one would be. The reason is that the micro-porous in the membrane would have different degrees of damaged when aerator has run certain time. With the aeration rate increase, the wind pressure in the micro-porous will become larger gradually [9]. As a result, the micro-porous expansion become larger and the SOTR become lower. On the other hand, because the micro -porous of old aerator will have different degrees of jam, the increase of aeration rate will make the micro-porous which have not been blocked bearing greater wind pressure. Finally, size of bubble increased and SOTR value reduce [10].

### *3.2. Cost analysis of aeration equipment between new aerator and old one*

The fan is composed of several sets of blower in practical application, so the total power depends on the blower quantity, operation characteristics and type of speed device, etc. In order to analyze the problem simply, the theory isothermal compression power calculation formula is used to calculate total power of blower system. The theory isothermal compression power calculation formula is show as follows:

$$Wp=Ne/e=\{(wRT_{\alpha}/eK)[(P_d/Pb)^k-1\}/2.665\times10^6 \qquad (3\text{-}1)$$

Ne --- Theory effective power, kw;
w --- Flow rate, kg/h (W=5.83 kg/$m^3$×$Q_s$=5.83$Q_s$);
$Q_s$ --- The actual standard flow rate on site, $m^3$/h;
R --- Ideal gas constant;
$T_a$ --- Blower inlet temperature, K;
$P_d$ --- Blower outlet pressure, Pa;
$P_b$ --- On-site pressure, Pa;
K --- (k-1)/k-0.283;
k --- Air fixed entropy coefficient, $C_p/C_v$=1.4;
e --- Blower total efficiency, %;

The ideal gas formula is:

$$P_b \times V_z = nRT_\alpha \tag{3-2}$$

The transformation formulas of quality flow rate and volume of flow rate is:

$$W=60Q_z/V_z \tag{3-3}$$

Calculation formula of blower power can be got from the above formulas:

$$Wp=(0.982\times10^{-6}Q_z\times P_b/e)\{[(P_b+P_d)/P_b]^{0.283}-1\} \tag{3-4}$$

Oxygen demand of clean water in aeration tank is:

$$Oc=(O_2\times Cs_{20})/[(\beta\times\tau\times\rho\times Cs_{20}-C_t)\times\alpha\times1.024^{T-20}] \tag{3-5}$$

$O_c$ --- Oxygen demand of clean water in aeration tank in standard condition, kg$O_2$/d;
$O_2$ --- Oxygen demand of wastewater in aeration tank in actual condition, kg$O_2$/d;
$C_{s20}$ --- Saturation dissolved oxygen values of distilled water in 20℃, 9.17 mg/L;
1.024 --- Temperature correction coefficient;
T --- Temperature in aeration tank, ℃;
$C_{s(T)}$ --- Saturation dissolved oxygen values of distilled water in T℃, mg$O_2$/L;
$C_t$ --- Dissolved oxygen values when aeration tank is in normal operation, mg$O_2$/L;
ρ --- Pneumatic correction coefficient in different areas;
τ --- Temperature correction coefficient, according to the following formula:

$$\tau=Cs_{(T)}/Cs_{(20)} \tag{3-6}$$

Total air supply can be calculated as follows:

$$Q_s=Q_c/(0.28\eta) \tag{3-7}$$

$Q_s$ --- Total air supply quantum, $m^3$/d
0.28 --- Oxygen content per cubic meter in standard condition (0.1Mpa，20℃);
η --- Oxygen utilization coefficient, %;

The design wind pressure of the fan is determined by the formula as follows:

$$P_d=P_1+P_2+P_3 \tag{3-8}$$

$P_d$ --- Required wind pressure, MPa;
$P_1$ --- Wind supply pipeline resistance, MPa;
$P_2$ --- Water static pressure above aeration air release point, MPa;
$P_3$ --- Aerator resistance, MPa

Operating costs of new aerator:

1. Oxygen demand of aeration tank in clean water under standard condition:

$$Oc = (O_2 \times Cs_{20}) / [(\beta \times \tau \times \rho \times Cs_{20} - C_t) \times \alpha \times 1.024^{T-20}]$$
$$= 2366 \times 9.17 / [(0.95 \times 1 \times 1 \times 9.17 - 2) \times 0.5 \times 1.024^{20-20}]$$
$$= 6465.386 \text{ kg/h}$$

2. Total air supply volume:

$$Qs = Qc / (0.28\eta) = 6465.386/(0.28 \times 0.41) = 56318.7 \text{ m}^3\text{/h}$$

3. Total wind pressure:

$$P_d = P_1 + P_2 + P_3 = 5.23 + 46.06 + 2.50 = 53.79 kPa$$

4. Aeration systempower:

$$Wp = (0.982 \times 10^{-6} Q_z \times P_b / e)\{[(P_b + P_d)/P_b]^{0.283} - 1\}$$
$$= (0.982 \times 10\text{-}6 \times 56318.7 \times 101000/0.74) \ \{[(101+53.79)/101]0.283\text{-}1\}$$
$$= 969.438 \text{ kw}$$

5. Present value of N years' electric costs:

$$POCST = USOWF \times Wp \times UPC \times 24 \times 365$$
$$= 0.95238 \times 969.438 \times 1.0 \times 24 \times 365$$
$$= 8087878.5 \text{ Yuan}$$

6. Present value of old aerators' electric costs:

$$POCST = USOWF \times Wp \times UPC \times 24 \times 365$$
$$= 0.95238 \times 1077.15 \times 1.0 \times 24 \times 365$$
$$= 8986530.6 \text{ Yuan}$$

Conclusions can be reached through the cost calculation:

1. If the aerator which had already been in operating more than 10 years continue run, the electric cost of aeration system is about 8.99 million Yuan per year. If replace the new one, the cost will decrease to about 8.09 million Yuan per year. So 0.9 million Yuan can be saved each year after replace the aerator which has already run more than 10 years.
2. The outfit aerators expenses and the aerators cost is about 1 million Yuan totally and this replacement can recovery its cost after only 14 months.

## 4. Conclusions

1. Compare with the new aerator, the SOTR of the aerator which has run for ten years decreased. And the greater aeration rate is, the more difference of SOTR between new aerator and old one is.
2. Micro-porous in the membrane will have different degrees of damaged when aerator has run certain time. And when the aeration rate increases, the wind pressure in the micro-porous will become larger gradually. As a result, the micro-porous expansion become larger and the SOTR become lower.
3. If the aerator which had already run more than 10 years will continue run, the electric cost of aeration system is about 8.99 million Yuan per year. When choose the same type of new aerator, the cost will decrease to about 8.09 million Yuan per year. So 0.9 million Yuan can be saved each year after replace the aerator which has already run more than 10 years.
4. The total expenses of aerators and their outfit is about 1 million Yuan and the replacement can recovery its cost after only 14 months.

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